ENGINE STARTING APPARATUS

Field of the Invention

[0001] The present invention relates to an engine starting apparatus for starting an engine at high speed (rpm) when a catalyst is in an inactive condition.

Background of Invention

[0002] Traditionally, series-wound DC motors, in which a field coil is connected in series with an armature coil, have often been employed as starter motors in engine starting apparatuses (refer to Japanese Unexamined Patent Publication No. 2000-125579). The output of this type of DC motor is determined based on the engine cranking torque, the lowest rotational speed capable of starting the engine, etc. so that a sufficient rotational speed can be obtained even in the wintertime (under extremely low temperature conditions).

[0003] However, when the engine is being started by the DC motor, as the engine starting speed (cranking rpm) is low, and the pressure of intake air being drawn into the cylinder is therefore low, fuel is not sufficiently atomized and the amount of fuel remaining in the intake port increases. Furthermore, at a low engine speed, the cylinder pressure is low even when compressed by the piston, and the amount of unatomized fuel remaining in the cylinder also increases.

[0004] As the engine speed increases thereafter, part of the remaining fuel is used for combustion, but as the air/fuel ratio becomes rich, much of the remaining fuel is exhausted as unburned gas. In particular, when a catalyst is in an inactive condition, such as when the engine is started from a cold condition, the remaining fuel may be emitted directly into the atmosphere because the purification performance of the catalyst is low.

[0005] One possible approach to reducing the amount of remaining fuel would be to reduce the amount of fuel

injection, but the amount of the remaining fuel is difficult to predict; therefore, if the amount of fuel injection is simply reduced, the engine starting performance may fall, depending on the properties of the fuel.

[0006] The present invention has been devised in view of the above situation, and an object of the invention is to provide an engine starting apparatus that can reduce emissions (HC) emitted into the atmosphere even when the catalyst is in an inactive condition.

Summary of Invention

(First aspect of the invention)

[0007] An engine starting apparatus using at least a starter according to a first aspect of the invention comprises catalyst condition judging means for judging whether a catalyst for purifying exhaust gas in the engine is in an inactive condition or not and, when the engine is being started, if the catalyst is judged to be in an inactive condition, the engine is started at higher speed than when the catalyst is in an active condition.

[0008] When the catalyst is in an inactive condition, if the engine is started at high speed, the engine speed increases compared with that in the normal condition (that is, when the catalyst is in an active condition); as a result, the amount of fuel remaining in the intake port and the cylinder decreases, and the injected fuel properly contributes to combustion. Accordingly, even when the catalyst is in an inactive condition, emissions (HC) emitted into the atmosphere can be reduced.

(Second aspect of the invention)

[0009] An engine starting apparatus according to a second aspect of the invention has a first starter having a high torque type output characteristic and a second starter having a high speed type output characteristic, and when starting the engine, if the catalyst is judged to be in an inactive condition, the engine is started by using the second starter.

[0010] When the catalyst is in an inactive condition, if the engine is started at high speed by using the second starter, the engine speed increases compared with that in the normal condition (that is, when the catalyst is in an active condition); as a result, the amount of fuel remaining in the intake port and the cylinder decreases, and the injected fuel properly contributes to combustion. Accordingly, even when the catalyst is in an inactive condition, the emissions emitted into the atmosphere can be reduced.

(Third aspect of the invention)

[0011] In the engine starting apparatus, the catalyst condition judging means judges that the catalyst is in an inactive condition when the temperature of the catalyst is lower than a predetermined temperature.

[0012] In this case, the catalyst can be reliably judged to be in an inactive condition because the condition of the catalyst (active condition/inactive condition) is judged based on the temperature of the catalyst itself. Accordingly, when the temperature of the catalyst is lower than the predetermined temperature, it is judged that the catalyst is in an inactive condition, and the emissions can be reduced by starting the engine at higher speed than when the catalyst is in an active condition.

(Fourth aspect of the invention)

[0013] In the engine starting apparatus, the catalyst condition judging means judges that the catalyst is in an inactive condition when oil temperature or coolant temperature of the engine is lower than a first predetermined temperature.

[0014] When the oil temperature or coolant temperature of the engine is low (lower than the first predetermined temperature), it is judged that the temperature of the catalyst is also low; therefore, in this case, it is judged that the catalyst is in an inactive condition, and the emissions can be reduced by cranking the engine at

higher speed than when the catalyst is in an active condition.

(Fifth aspect of the invention)

[0015] In the engine starting apparatus, the catalyst condition judging means judges that the catalyst is in an inactive condition when the engine has been in a stopped condition for more than a predetermined length of time.

[0016] When the time elapsed from the time that the engine was last stopped is long (longer than a predetermined length of time), it is judged that the temperature of the catalyst is low; therefore, in this case, it is judged that the catalyst is in an inactive condition, and the emissions can be reduced by starting the engine at higher speed than when the catalyst is in an active condition.

(Sixth aspect of the invention)

[0017] The engine starting apparatus is used in an engine automatic stopping/starting system which automatically controls the stopping and restarting of the engine, and its catalyst condition judging means judges that the catalyst is in an inactive condition when the engine is started by operating an ignition key but not when the engine is restarted by the engine automatic stopping/starting system.

[0018] In the system that automatically controls the stopping and restarting of the engine, it is judged that the catalyst is in an active condition when the engine is restarted (by automatic control). On the other hand, when the driver starts the engine by operating the ignition key, it is judged that the catalyst is in an inactive condition; therefore, in this case (when the engine is started by operating the ignition key), it is judged that the catalyst is in an inactive condition, and the emissions can be reduced by driving the engine at higher speed than when the catalyst is in an active condition.

(Seventh aspect of the invention)

[0019] The engine starting apparatus includes motor control means for controlling an output characteristic of a motor provided in the starter, and the motor control means changes the output characteristic of the motor to a high speed type, thereby allowing the engine to be driven at high speed.

[0020] When the engine is driven at high speed by changing the output characteristic (torque-rpm) of the motor to the high-speed-type, the engine speed increases compared with that in the normal condition, and thus the emissions can be reduced.

(Eighth aspect of the invention)

[0021] In the engine starting apparatus, the motor control means controls the output characteristic of the motor to the high speed type by changing the field current of the motor.

[0022] As the output characteristic of the motor can be controlled based on the field current of the motor, the engine can be cranked at high speed by performing control to change the field current, thereby switching the output characteristic of the motor to the high speed type.

(Ninth aspect of the invention)

[0023] In the engine starting apparatus, the motor has a series coil and a shunt coil, and the motor control means comprises an energization circuit which can energize the shunt coil in such a manner that the field current flowing in the shunt coil is opposite in direction to the field current flowing in the series coil, wherein the motor control means reduces the field current of the motor by controlling through the energization circuit at least either the amount of the current or the direction of the current flowing in the shunt coil.

[0024] If the field current of the shunt coil is reduced, sufficiently high engine speed may not be achieved because of the influence of the magnetic flux

produced in the series coil. In this case, by energizing the shunt coil in such a manner that the field current flowing in the shunt coil is opposite in direction to the field current flowing in the series coil, the influence of the magnetic flux produced in the series coil can be cancelled out, and a sufficiently high engine speed can be achieved. As a result, the engine can be driven at high speed.

(10th aspect of the invention)

[0025] In the engine starting apparatus, the motor control means includes a field current reducing means capable of reducing the field current flowing in a field coil (series coil) of the motor, and the motor control means reduces the field current of the motor by using the field current reducing means.

[0026] By using the field current reducing means to reduce the field current flowing in the field coil (series coil) of the motor, the output characteristic of the motor can be controlled to the high speed type, so that the engine can be started at high speed.

(11th aspect of the invention)

[0027] In the engine starting apparatus, the motor control means reduces the field current of the motor in accordance with speed of the engine or the starter.

[0028] As the field current is controlled in accordance with the speed of the engine or the starter, the engine can be driven properly at high speed.

(12th aspect of the invention)

[0029] In the engine starting apparatus, the motor control means reduces the field current of the motor in accordance with a crankshaft position in the engine.

[0030] As the field current is controlled in accordance with the engine crankshaft position, the engine can be driven more properly at high speed by suppressing the effects of the torque/rpm variations associated with the piston intake-compression-expansion-exhaust strokes.

(13th aspect of the invention)

[0031] In the engine starting apparatus, the motor control means reduces the field current of the motor after a piston reaches the top dead center in any one of cylinders after the starting of the engine.

[0032] After the starting of the engine, air substantially at atmospheric pressure continues to be compressed in the engine until after a piston reaches the top dead center in any one of the cylinders; therefore, during this period, large torque is required to start the engine.

[0033] However, once a piston reaches the top dead center in any one of the cylinders, the engine itself generates driving force because of the expansion that follows the compression, and the large torque for driving the engine is no longer necessary. In view of this, before a piston reaches the top dead center in any one of the cylinders, an increase in the field current switches the output characteristic of the starter to the high torque type, and then, after a piston reaches the top dead center is reached in any one of the cylinders, a reduction in the field current switches the output characteristic of the starter to the high speed type so that the engine can be properly driven at high speed.

(14th aspect of the invention)

[0034] In the engine starting apparatus, the motor control means sets an electric current value that maximizes the output of the motor as a control target value for the field current.

[0035] If the output of the motor can be maximized by controlling the field current, the engine can be started at maximum speed, and hence, the emission reducing effect can be maximized.

(15th aspect of the invention)

[0036] In the engine starting apparatus according to any one of the eighth to 14th aspects, the motor control means stops the field current reducing control when the

oil temperature or the coolant temperature of the engine is lower than a second predetermined temperature which is lower than the first predetermined temperature for judging whether the catalyst is in an inactive condition or not.

[0037] At extremely low temperatures, the viscosity of the engine oil increases, and higher engine torque may be required when starting the engine. Accordingly, when the oil temperature or coolant temperature of the engine is lower than the predetermined temperature (second predetermined temperature) below which higher engine torque is required, the field current reducing control is stopped, and the motor is driven with a high torque type characteristic so that the engine can be started properly even at extremely low temperatures.

(16th aspect of the invention)

[0038] In the engine starting apparatus, the motor control means stops reducing the field current when oil temperature or coolant temperature of the engine is higher than a third predetermined temperature which is higher than the first predetermined temperature for judging whether the catalyst is in an inactive condition or not.

[0039] In high temperature conditions, such as when the engine is stopped after heavy load driving such as uphill driving, and the engine is restarted immediately after that, the cylinder is sealed more tightly, requiring higher engine torque when starting the engine. Accordingly, when the oil temperature or coolant temperature of the engine is higher than the predetermined temperature (third predetermined temperature) above which higher engine torque is required, it is stopped to reduce the field current, and the motor is driven with a high torque type characteristic so that the engine can be started properly even at extremely high temperatures.

(17th aspect of the invention)

[0040] In the engine starting apparatus, the motor control means stops reducing the field current when the speed of the engine or the starter has failed to reach a predetermined speed.

[0041] When the engine is driven at high speed by reducing the field current of the motor, if the engine speed does not rise for some reason, reduction of the field current is stopped, and the motor is driven with a high torque type characteristic so that the engine can be properly even in a faulty condition.

(18th aspect of the invention)

[0042] In the engine starting apparatus, the motor control means stops reducing the field current when the battery is at low state of charge.

[0043] When the battery is at low state of charge, such as when the vehicle has been left standing for an extended period of time, the output of the starter drops. Accordingly, when the battery is at low state of charge, the field current is not reduced, and the motor is driven with a high torque type characteristic so that the engine can be driven properly.

(19th aspect of the invention)

[0044] In the engine starting apparatus, a power supply means for supplying field current to the shunt coil is provided separately from a battery, and the motor control means stops reducing the field current when the power supply means is at lower stage of charge than a predetermined level.

[0045] A separate power supply (for example, a capacitor) may be provided to energize the field coil (shunt coil) in order to prevent the battery voltage from dropping due to a large current flow to the motor when controlling the field current of the motor. Here, if the separate power supply (power supply means) is at lower state of charge than the predetermined battery charge level, the magnetic field necessary for driving the motor cannot be formed; in that case, the field current for the

shunt coil is not reduced so that the engine can be driven properly.

(20th aspect of the invention)

[0046] In the engine starting apparatus, the motor provided in the starter is a DC motor.

[0047] By using a DC motor, the system of the present invention can be implemented in a simple manner and at low cost.

(21st aspect of the invention)

[0048] In the engine starting apparatus, the engine is started by using the first starter when the oil temperature or the coolant temperature of the engine is lower than a second predetermined temperature which is lower than the first predetermined temperature for judging whether the catalyst is in an inactive condition or not.

[0049] At extremely low temperatures, the viscosity of the engine oil increases, and higher engine torque may be required when starting the engine. Accordingly, when the oil temperature or coolant temperature of the engine is lower than the predetermined temperature (second predetermined temperature) below which higher engine torque is required, the second starter having the high speed type output characteristic is not used, but the first starter having the high torque type output characteristic is switched in to start the engine; by so doing, the engine can be started properly even at extremely low temperatures.

(22nd aspect of the invention)

[0050] In the engine starting apparatus, the engine is started by using the first starter when the oil temperature or the coolant temperature of the engine is higher than a third predetermined temperature which is higher than the first predetermined temperature for judging whether the catalyst is in an inactive condition or not.

[0051] In high temperature conditions, such as when

the engine is stopped after heavy load driving such as uphill driving, and the engine is restarted immediately, the cylinder is sealed more tightly, requiring higher engine torque when starting the engine. Accordingly, when the oil temperature or coolant temperature of the engine is higher than the predetermined temperature (third predetermined temperature) above which higher engine torque is required, the second starter having the high speed type output characteristic is not used, but the first starter having the high torque type output characteristic is switched in to start the engine; by so doing, the engine can be started properly even at extremely low temperatures.

(23rd aspect of the invention)

[0052] In the engine starting apparatus, when the engine was started by using the second starter, if the speed of the engine or the second starter failed to reach a predetermined speed, the engine is started by switching from the second starter to the first starter.

[0053] When the engine is started by using the second starter having the high speed type output characteristic, if the engine rpm does not rise for some fault, the second starter is stopped, and the first starter having the high torque type output characteristic is switched in to start the engine; by so doing, the engine can be started properly even in a faulty condition.

(24th aspect of the invention)

[0054] In the engine starting apparatus, the engine is started by using the first starter when a battery is at low stage of charge.

[0055] When state of charge the battery is at low stage of charge, such as when the vehicle has been left standing for an extended period of time, the second starter having the high speed type output characteristic is not used, but the first starter having the high torque type output characteristic is switched in to start the engine; by so doing, the engine can be started properly.

(25th aspect of the invention)

[0056] In the engine starting apparatus, when the engine speed is higher than a predetermined speed, the amount of fuel injection is reduced compared with a case where the catalyst is in an active condition.

[0057] When the engine speed is higher than the predetermined speed, the air/fuel ratio for combustion becomes rich, because the amount of fuel remaining in the intake port and the cylinder decreases; therefore, if the same amount of fuel as that in the case of normal engine starting (engine starting when the catalyst is in an active condition) is injected, unburned gas will be emitted. Accordingly, by reducing the amount of fuel injection compared with that of the normal case, the amount of unburned gas emitted can be reduced, and the emissions can thus be reduced.

(26th aspect of the invention)

[0058] In the engine starting apparatus, when the speed of the engine is higher than the predetermined speed, the amount of fuel injection is reduced depending on air/fuel ratio.

[0059] By reducing the amount of fuel injection depending on air/fuel ratio, the emissions can be further reduced.

(27th aspect of the invention)

[0060] In the engine starting apparatus, fuel injection is started after it is detected that intake manifold pressure in the engine is lower than a predetermined value.

[0061] If the engine intake manifold pressure is high, the fuel is not sufficiently atomized and the air/fuel mixture in the intake port cannot be properly introduced into the cylinder. Therefore, by starting the fuel injection after detecting that the engine intake manifold pressure is lower than the predetermined value, the amount of unburned gas in the intake port can be reduced, which contributes to reducing the emissions.

(28th aspect of the invention)

[0062] In the engine starting apparatus, fuel injection is started after it is detected that the number of revolutions of the engine is higher than a predetermined speed.

[0063] If the engine speed is higher than the predetermined speed, the air/fuel mixture in the intake port can be properly introduced into the cylinder, and the emissions can thus be reduced.

(29th aspect of the invention)

[0064] In the engine starting apparatus, fuel injection is started after it is detected that the total rpm of the engine counted from the starting of the engine has reached a predetermined value.

[0065] If the total rpm of the engine counted from the starting of the engine is larger than the predetermined value, it is expected that the intake manifold pressure is sufficiently low; therefore, the air/fuel mixture in the intake port can be properly introduced into the cylinder, and the emissions can thus be reduced.

(30th aspect of the invention)

[0066] In the engine starting apparatus, fuel injection is started after it is detected that a predetermined time has elapsed from the starting of the engine.

[0067] If the predetermined time has elapsed from the starting of the engine, it is expected that the intake manifold pressure is sufficiently low; therefore, the air/fuel mixture in the intake port can be properly introduced into the cylinder, and the emissions can thus be reduced.

(31st aspect of the invention)

[0068] In the engine starting apparatus, when starting the engine by driving the engine at high speed, a threshold speed for perfect combustion is changed according to the engine speed.

[0069] When the engine is started at high speed, the

engine may continue to be driven beyond the threshold speed for perfect combustion which is used in normal engine starting (engine starting when the catalyst is in an active condition). In view of this, when starting the engine by driving it at high speed, the threshold speed for perfect combustion is changed according to the engine speed; this ensures proper starting of the engine.

(32nd aspect of the invention)

[0070] In the engine starting apparatus, when the engine speed has reached the threshold speed for perfect combustion, operation of the starter is stopped.

[0071] In the case of a system that automatically starts the starter of the present invention, the engine can be started properly if the driving by the starter is stopped when the engine speed has reached the threshold speed for perfect combustion.

[0072] Other features and advantages will become apparent in discussion of the embodiments of the invention in relation to the following drawings.

BRIEF DESCRIPTION OF DRAWINGS

[0073] FIG. 1 is an electrical circuit diagram of an engine starting apparatus.

[0074] FIG. 2 is a diagram showing starter output characteristics.

[0075] FIG. 3 is a flowchart illustrating the operation of the engine starting apparatus (first embodiment).

[0076] FIG. 4 is a time chart for explaining the operation and effect (HC reduction) of the embodiment.

[0077] FIG. 5 is a flowchart illustrating the operation of the engine starting apparatus (second embodiment).

[0078] FIG. 6 is a flowchart illustrating the operation of the engine starting apparatus (third embodiment).

[0079] FIG. 7 is an electrical circuit diagram of an engine starting apparatus (third embodiment).

[0080] FIG. 8 is an electrical circuit diagram of an engine starting apparatus (fourth embodiment).

Embodiments of Invention

[0081] Embodiments of the present invention will be described below with reference to the drawings.

(Embodiment 1)

[0082] FIG. 1 is an electrical circuit diagram of an engine starting apparatus.

[0083] The engine starting apparatus A of this embodiment is used in the so-called idle stop system which automatically stops the engine when the vehicle comes to a stop, for example, at an intersection or in traffic jam, and restarts the engine (not shown) when a prescribed starting condition is satisfied (for example, when the driver releases the brake pedal and steps on the accelerator pedal); the engine starting apparatus is equipped with a starter 1 for starting the engine and is controlled by an Electronic Control Unit (ECU) 2 (which contains motor control means of the present invention).

[0084] The starter 1 comprises a compound-wound DC motor, the rotational output of which is transmitted to the engine to start the engine. The starter 1 may be of a gear drive type which brings the pinion gear into engagement with the engine ring gear, or of a belt drive type which transmits the output of the starter 1 to the engine by means of a drive belt.

[0085] The DC motor has a series coil 4 connected in series with an armature 3, and a shunt coil 6 connected to an energization circuit 5 described below, and is energized by being connected to a vehicle battery 10 via a starter relay 8 and an electromagnetic switch 9 when an ignition key 7 is turned on (to position ST).

[0086] The energization circuit 5 comprises four control elements 11 (for example, MOS-FETs) connected in the form of a bridge, whose one input terminal 5a is connected to the positive terminal of the vehicle battery 10 via the electromagnetic switch 9, and whose other

input terminal 5b is grounded.

[0087] The ECU 2 controls the field current flowing in the shunt coil 6 by controlling the energization circuit 5. More specifically, the ECU 2 controls the amount and direction of the current flowing in the shunt coil 6 (the current can be made to flow in the direction opposite to the direction of the current in the series coil 4) in accordance with the duty cycle of each control element 11 in the energization circuit 5. As a result, as shown in Figure 2, the output characteristic of the DC motor becomes a higher speed type as the field current decreases, and a higher torque type as the field current increases.

[0088] Next, the operation of the engine starting apparatus A will be described with reference to the flowchart shown in Figure 3.

[0089] Step 10: Presence or absence of a start request is checked. Here, when a restart request is detected after automatic stopping of the engine, it is decided that a start request has occurred. If the result of the decision is YES, the process proceeds to the next step 20, but if the result of the decision is NO, the process is terminated.

[0090] Step 20: Decision is made as to whether the catalyst for purifying the exhaust gas is in an inactive condition or not. The inactive condition of the catalyst is detected based on the following criteria.

[0091] a) The catalyst temperature is lower than a predetermined temperature (for example, 300°C).

[0092] b) The oil temperature or coolant temperature of the engine is lower than a first predetermined temperature (for example, 60°C).

[0093] c) The engine has been in a stopped condition for more than a predetermined length of time (for example, 10 minutes).

[0094] If the result of the decision is NO, the process proceeds to the next step 30, but if the result

of the decision is YES, the process proceeds to step 60.

[0095] Step 30: Duty cycle of each control element 11 in the energization circuit 5 is controlled (increased) so as to increase the field current flowing in the shunt coil 6.

[0096] Step 40: Starter 1 is turned on.

[0097] Step 50: After performing normal engine control, the process proceeds to step 140.

[0098] Step 60: Duty cycle of each control element 11 in the energization circuit 5 is controlled (increased) so as to increase the field current flowing in the shunt coil 6.

[0099] Step 70: Starter 1 is turned on.

[0100] Step 80: Decision is made as to whether top dead center is detected in any one of the cylinders. If top dead center is detected (the result of the decision is YES), the process proceeds to step 90.

[0101] Step 90: Duty cycle of each control element 11 in the energization circuit 5 is controlled (decreased) so as to reduce the field current flowing in the shunt coil 6. In this case, the duty cycle of each control element 11 may be decreased gradually in order to prevent shock that may be caused due to an abrupt change in the output characteristic of the starter 1.

[0102] Step 100: Decision is made as to whether the engine rpm has exceeded a predetermined rpm N. Here, whether the engine rpm has increased up to the rpm at which fuel injection can be started is determined by reference to the predetermined rpm N. When the engine rpm has exceeded the predetermined rpm N (the result of the decision is YES), the process proceeds to step 110.

[0103] Step 110: The amount of fuel injection is reduced compared with that in normal engine control. More specifically, the amount of fuel injection is determined from the current engine rpm by referring to a map. In Step 110, the amount of fuel injection may be controlled based on the air/fuel ratio.

[0104] Step 120: Fuel injection to engine is started.

[0105] Step 130: Threshold rpm S for perfect combustion is determined from the current engine rpm by referring to a map.

[0106] Step 140: Decision step 140 is repeated until the current engine rpm exceeds the threshold rpm S for perfect combustion determined in step 130. When the threshold rpm S for perfect combustion is exceeded (the result of the decision is YES), the process proceeds to step 150.

[0107] Step 150: Starter 1 is turned off, whereupon the process is terminated.

(Effect of Embodiment 1)

[0108] According to the present embodiment, when the catalyst is in an inactive condition, first, the engine is driven by controlling the output characteristic of the starter 1 to the high torque type (by increasing the field current), as shown in FIG. 4(a), and then, after top dead center is reached in any one of the cylinders, the output characteristic of the starter 1 is controlled to the high speed type by reducing the field current of the motor, thereby making it possible to properly drive the engine at high speed. As a result, as the engine rpm during cranking rises compared with the normal case (the case where the catalyst is in an active condition), as shown in Figure 4(b), the amount of fuel remaining in the intake port and the cylinder decreases, and the injected fuel properly contributes to combustion. Accordingly, even when the catalyst is in an inactive condition (the purification performance is low), emissions (HC) emitted into the atmosphere can be reduced (see Figure 4(c)).

[0109] Further, when the engine rpm is higher than the predetermined rpm N, the air/fuel ratio for combustion becomes rich, because the amount of fuel remaining in the intake port and the cylinder decreases; therefore, if the same amount of fuel as that in the case of normal engine starting (engine starting when the catalyst is in an

active condition) is injected, unburned gas will be emitted. Accordingly, by reducing the amount of fuel injection compared with the case of normal engine control, the amount of unburned gas emitted can be reduced, which contributes to further reducing the emissions.

[0110] The first embodiment has been described by assuming the case where the engine is restarted after automatic stopping but, even when starting the engine by activating the starter 1 through operation of the ignition key 7, the same effect as achieved in the first embodiment can be obtained by reducing the field current of the motor and thereby driving the engine at high speed when the catalyst has been judged to be in an inactive condition. In this case, besides the previously given criteria a) to c) for judging the inactive condition of the catalyst, it may be judged that the catalyst is in an inactive condition when the engine is started by operating the ignition key 7.

(Embodiment 2)

[0111] Figure 5 is a flowchart illustrating the operation of the engine starting apparatus A.

[0112] In this embodiment, steps 80/90 and 100A are performed instead of the steps 80 to 100 shown in the flowchart described in the first embodiment. Otherwise, the process (steps 10 to 70 and 110 to 150) is the same as that of the first embodiment (the description will not be repeated here).

[0113] Details of the steps 80/90 and 100A will be described below.

[0114] Step 80/90: The field current of the motor is reduced compared with the normal case (the case where the catalyst is in a normal condition). More specifically, the field current is determined from the current engine rpm or starter rpm by referring to a map.

[0115] Step 100A: Decision is made as to whether or not intake manifold pressure is either equal to or higher

than a predetermined value p. If the intake manifold pressure is higher than the predetermined value p (the result of the decision is NO), the process returns to step 80/90, but if the intake manifold pressure is not higher than the predetermined value p (the result of the decision is YES), the process proceeds to step 110.

[0116] According to the present embodiment, as the field current is reduced according to the rpm of the engine or the starter 1, the engine can be properly cranked at high rpm.

[0117] Furthermore, as fuel injection starts after detecting that the engine intake manifold pressure is not higher than the predetermined value p, the air/fuel mixture in the intake port can be properly introduced into the cylinder, reducing the amount of unburned gas in the intake port; this contributes to reducing the emissions more reliably.

[0118] In the present embodiment, a decision is made in step 100A as to whether the intake manifold pressure is not higher than the predetermined value p, but instead, decision may be made as to whether the total number of revolutions counted from the starting of the engine has reached a predetermined value in order to start the fuel injection after the predetermined value has been reached. Alternatively, a decision may be made as to whether a predetermined time has elapsed from the starting of the engine in order to start the fuel injection after the predetermined time has elapsed.

[0119] In these cases, as it is judged that the intake manifold pressure is sufficiently low, the air/fuel mixture in the intake port can be properly introduced into the cylinder, and thus, the emissions can be reduced.

(Embodiment 3)

[0120] Figure 6 is a flowchart illustrating the operation of the engine starting apparatus A.

[0121] This embodiment concerns an example, in which

control of the reduction of the field current is stopped and is changed to the normal engine control.

[0122] The details of the control according to this embodiment will be described below with reference to the flowchart.

[0123] Steps 10 to 70: Same as the corresponding steps in the first embodiment (refer to the description of the first embodiment).

[0124] Step 80: The field current of the motor is reduced compared with that in the normal condition (that is, when the catalyst is in an active condition). More specifically, the field current is determined from the current engine rpm or starter rpm by referring to a map.

[0125] Step 90: The state of charge of the battery 10 is checked. If the state of charge is low (the result of the decision is NO), the field current reducing control is stopped, and the process proceeds to step 30 to switch to the normal engine control. If the state of charge is high (the result of the decision is YES), the process proceeds to the next step 100.

[0126] Step 100: Decision is made as to whether the engine coolant temperature (or oil temperature) lies within a range not lower than a second predetermined temperature T1 (for example, -10°C) and not higher than a third predetermined temperature T2 (for example, 100°C). If the result of the decision is NO, that is, if the temperature is lower than the second predetermined temperature T1 or higher than the third predetermined temperature T2, the field current reducing control is stopped, and the process proceeds to step 30 to switch to the normal engine control. If the result of the decision is YES, the process proceeds to the next step 110.

[0127] Step 110: Decision is made as to whether the engine rpm or starter rpm is lower than a predetermined rpm M. If the result of the decision is YES, the field current reducing control is stopped, and the process proceeds to step 30 to switch to the normal engine

control. If the result of the decision is NO, the process proceeds to the next step 120.

[0128] Steps 120 to 170: Same as steps 100 to 150 in the first embodiment (or steps 100A to 150 in the second embodiment) (refer to the description of the first embodiment).

[0129] The present embodiment, when any one of the following conditions a) to d) is satisfied, stops reducing the field current, and switches to the normal engine control so that the engine can be cranked properly.

[0130] a) The battery 10 is at low state of charge.

[0131] When the battery 10 is at low state of charge, such as when the vehicle has been left standing for an extended period of time, the output of the starter 1 drops. Accordingly, when the battery 10 is at low state of charge, the field current is not reduced, and the motor is driven with a high torque type characteristic so that the engine can be started properly.

[0132] b) The coolant temperature of the engine is lower than the second predetermined temperature T1.

[0133] At extremely low temperatures, the viscosity of the engine oil increases, requiring higher engine cranking torque when starting the engine. Accordingly, when the coolant temperature or oil temperature of the engine is lower than the second predetermined temperature T1 below which higher engine torque is required, the field current is not reduced, and the motor is driven with a high torque type characteristic so that the engine can be driven properly even at extremely low temperatures.

[0134] c) The coolant temperature of the engine is higher than the third predetermined temperature T2.

[0135] In high temperature conditions, such as when the engine is stopped after heavy load driving such as uphill driving, and the engine is restarted immediately, the cylinder is sealed more tightly, requiring higher

engine torque when starting the engine. Accordingly, when the coolant temperature or oil temperature of the engine is higher than the third predetermined temperature T2 above which a higher engine torque is required, the field current is not reduced, and the motor is driven with a high torque type characteristic so that the engine can be driven properly even at extremely high temperatures.

[0136] d) Engine rpm is lower than the predetermined rpm M.

[0137] When the engine is driven at high speed by reducing the field current of the motor, if the engine rpm does not rise (remains lower than the predetermined rpm M) for some fault, the field current is not reduced, and the motor is driven with a high torque type characteristic so that the engine can be driven properly even in a faulty condition.

[0138] In the electrical circuit diagram shown in Figure 1, battery voltage is applied to the energization circuit 5 that controls the field current of the shunt coil 6, but alternatively, as shown in Figure 7, a separate power supply 12 (power supply means of the present invention) for energizing the shunt coil 6 may be used. This has the merit of being able to prevent the battery voltage from dropping due to a large current flow to the armature 3 when controlling the field current of the shunt coil 6.

[0139] When the separate power supply 12 (for example, a capacitor) is used, if the state of charge of the separate power supply 12 is lower than the required level, the magnetic field necessary for driving the motor cannot be formed; in that case, the field current reducing control is stopped, and the motor is driven with a high torque type characteristic so that the engine can be driven properly even in a faulty condition.

(Embodiment 4)

[0140] This embodiment concerns an example in which

field current is controlled in a series-wound motor that does not have a shunt coil.

[0141] Figure 8 is an electrical circuit diagram of an engine starting apparatus B.

[0142] In the engine starting apparatus B of this embodiment, the motor has two sets of field coils 4 (series coils), and a normally closed relay 13 (field current reducing means of the present invention) is provided between the armature 3 and one set of field coils 4a.

[0143] Here, when a switch 13b of the normally closed relay 13 is in the closed condition, both the field coils 4a and 4b are energized, so that the field current increases and the engine can be driven with high torque. On the other hand, when the switch 13b is opened by energizing a coil 13a of the normally closed relay 13 under control of the ECU 2, the field current flows only in the other set of field coils 14b; as a result, the field current decreases compared with the case where the switch 13b is closed, and the engine can thus be driven at high speed.

[0144] The engine starting apparatus B of this embodiment offers the same effect as achieved in the first to third embodiments, that is, the emissions (HC) can be reduced by reducing the motor field current and driving the engine at high speed when the catalyst is in an inactive condition.

(Modification)

[0145] The first to fourth embodiments have each dealt with the configuration in which the output characteristic of the single starter 1 is varied, but alternatively, two starters may be used, the first starter having a high torque type output characteristic and the second starter having a high speed type output characteristic. In this case, by using the second starter when the catalyst is in an inactive condition, the engine can be cranked at high rpm, as in the first to fourth embodiments. Furthermore,

when any one of the conditions to stop reducing the field current, described in the third embodiment is satisfied, the second starter is stopped and the first starter is switched in to start the engine at high torque; this ensures reliable driving of the engine.